FORM PTO-1390 U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE REV. 2/01T **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371**	ATTORNEY'S DOCKET NUMBER 08364 0036 Customer No.: 22,852
	U.S APPLICATION NO (If known, see 37CFR1 5) **10/031948**

INTERNATIONAL APPLICATION NO. **PCT/GB00/02898**	INTERNATIONAL FILING DATE **July 27, 2000**	PRIORITY DATE CLAIMED **July 27, 1999**

TITLE OF INVENTION: **FOURIER TRANSFORM SPECTROMETER USING AN OPTICAL BLOCK**

APPLICANTS FOR DO/EO/US: **1) Robert JONES, and 2) Michael Stuart HAZELL**

Applicants herewith submit to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S C 371.

2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.

4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).

5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c)(2)).
     a. ☒ is attached hereto (required only if not communicated by the International Bureau.
     b. ☒ has been communicated by the International Bureau.
     c. ☐ is not required, as the application was filed with the United States Receiving Office (RO/US).

6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371 (c)(2)).
     a. ☐ is attached hereto.
     b. ☐ has been previously submitted under 35 U.S.C. 154 (d)(4).

7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3)).
     a. ☐ are attached hereto (required only if not communicated by the International Bureau).
     b. ☐ have been communicated by the International Bureau.
     c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
     d. ☒ have not been made and will not be made.

8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).

9. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).

10. ☒ The annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. ☒ Information Disclosure Statement under 37 CFR 1.97 and 1.98

12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. ☒ A FIRST preliminary amendment.

14. ☐ A SECOND or SUBSEQUENT preliminary amendment.

15. ☐ A Substitute specification.

16. ☐ A change of power of attorney and/or address letter.

17. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821-1.825.

18. ☐ A second copy of the published international application under 35 U.S.C. 154 (d)(4).

19. ☐ A second copy of the English language translation of the international application 35 U.S.C. 154 (d)(4).

20. ☒ Other items or information:
     a. ☒ Copy of cover page of International Publication No. WO 01/07879 A1.
     b. ☐ Copy of Notification of Missing Requirements.
     c. ☒ Abstract of the Disclosure.

U.S. APPLICATION NO (If known, see 37CFR 1 5) 10/031948	INTERNATIONAL APPLICATION NO PCT/GB00/02898	ATTORNEY'S DOCKET NUMBER: 08364 0036

21. ☒ The following fees are submitted:	CALCULATIONS PTO USE ONLY

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):

Neither international preliminary examination fee (37 CFR 1.482)
nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO
and International Search Report not prepared by the EPO or JPO **$1040.00**

International preliminary examination fee (37 CFR 1.482) not paid to
USPTO but International Search Report prepared by the EPO or JPO **$890.00**

International preliminary examination fee (37 CFR 1.482) not paid to
USPTO but International Search fee (37 CFR 1.445(a)(2)) paid to USPTO **$740.00**

International preliminary examination fee (37 CFR 1.482) paid to USPTO
but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$710.00**

International preliminary examination fee (37 CFR 1.482) paid to
USPTO and all claims satisfied provisions of PCT Article 33 (1)-(4) **$100.00**

			ENTER APPROPRIATE BASIC FEE AMOUNT =	$890.00	

Surcharge of $130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).				$	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total Claims	30 − 20 =	10	x $18.00	$180.00	
Independent Claims	2 −3 =	0	x $84.00	$	
☒ MULTIPLE DEPENDENT CLAIMS (if applicable)			+$280.00	$280.00	

			TOTAL OF THE ABOVE CALCULATIONS =	$1350.00	
☐ Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by ½.				$	
			SUBTOTAL =	$1350.00	

Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest priority date (37 CFR 1.492(f)).				$	

			TOTAL NATIONAL FEE =	$1350.00	

Fee for recording the enclosed assignment (37 CFR 1.21 (h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property. +				$	

			TOTAL FEES ENCLOSED =	$1350.00	
				Amount to be refunded:	$
				charged:	$

a.   ☒   A check in the amount of $ ___1350.00___ to cover the above fees is enclosed.

b.   ☐   Please charge my Deposit Account No. _____ in the amount of $ _____ to cover the above fees.
A duplicate copy of this sheet is enclosed.

c.   ☒   The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to
Deposit Account No. _06-0916._   A duplicate copy of this sheet is enclosed.

d.   ☐   Fees are to be charged to a credit card. **WARNING: Information on this form may become public. Credit card
information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b))
must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

Finnegan, Henderson, Farabow, Garrett & Dunner, L.L.P.
1300 I Street, N.W.
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EFC/FPD/sci
DATED: January 25, 2002

SIGNATURE

Ernest F. Chapman/25,961
NAME/REGISTRATION NO.

PATENT
Attorney Docket No. 08364.0036
CUSTOMER NUMBER 22,852

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of:)
)
Robert JONES et al.) Group Art Unit: Not Yet Assigned
)
Serial No.: Not Yet Assigned) Examiner: Not Yet Assigned
)
Filed: January 25, 2002)
)
National Stage of International Application)
No. **PCT/GB00/02898**, under 35 U.S.C.)
371, for **FOURIER TRANSFORM
SPECTROMETER USING AN OPTICAL
BLOCK**

**Assistant Commissioner for Patents
Washington, DC 20231**

Sir:

PRELIMINARY AMENDMENT

Prior to examination, please amend the above-identified application as follows:

IN THE SPECIFICATION:

Please amend the specification as follows:

Page 1, after the title insert a new paragraph as follows:

--CROSS REFERENCE TO RELATED APPLICATIONS

This application is a national phase application based on international application

number **PCT/GB00/02898**, filed on July 27, 2000, and claims the priority of British

Patent Application No. 9917610.9, filed on July 27, 1999.--

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IN THE CLAIMS:

Please replace now pending claims 1-19 without prejudice or disclaimer and substitute new claims 20-39 therefor as follows:

WHAT IS CLAIMED IS:

20.   (New) An interferometric optical block having three planar nominally parallel surfaces with the two outer surfaces adapted to act as beam reflectors for internal light and the third surface in operation acting as a beam splitter and beam combiner, the optical block having an input portion by means of which an input beam of light to be analysed can be input so as partially to pass through said third surface to be internally reflected by one of said outer reflectors, and partially to be reflected by said third surface so as then to be internally reflected by the other of said outer reflectors whereby light internally reflected by said outer reflectors is combined at said third surface to produce an exit beam, and wherein said outer surfaces have an inclination with respect to one another and are asymmetric with respect to said third surface so as to generate in the exit beam a linear fringe field distributed about the zero-order fringe.

21.   (New) An optical block in accordance with claim 20, in which the exit beam results from the interference of the beams transmitted and reflected from the beam splitter/combiner

that have in operation each undergone a single reflection at the outer reflectors.

22.   (New) An optical block in accordance with claims 20, which has been fabricated by cutting a single wedge element parallel to the wedge section to create two identical wedges and with one such wedge so cut rotated 180°, the lower face of said one wedge

being secured to the other wedge to form a monolithic element which provides said optical block, the adjacent faces of the wedges forming said third surface.

23.   (New) An optical block in accordance with claim 20, in which the exit beam in operation results from the interference of beams combined at the beam splitter/combiner which have undergone two reflections at the outer reflectors.

24.   (New) An optical block in accordance with claim 20, in which the beam splitter/combiner and one reflector are formed by an optical flat with parallel faces and the other reflector is provided by a single unit comprising the inclined mirror or mirrors and an integral location for the optical flat.

25.   (New) An optical block in accordance with claim 20, in which the beam splitter/combiner and one reflector are formed by an optical flat with parallel faces and the other reflector by a solid prism with one plane face and an inclined second face, the block having been assembled by attaching the plane face of the solid prism to the plane beam splitter/combiner face of the optical flat.

26.   (New) An optical block in accordance with claim 20, fabricated from two identical solid dual angle prisms where the plane faces are attached to form the beam splitter combiner and the outer identical and mutually inclined faces form the reflectors.

27.   (New) An optical block in accordance with claim 26, in which the prisms have been obtained by cutting in two a single dual angle prism in a plane parallel to the dual angle section.

28.   (New) An optical block according to any one of the preceding claims, wherein in order to maximise optical throughput over the spectral range of operation, said beam splitter/combiner and reflector surfaces are coated with a coating such that the reflectivity coefficient of the reflectors is approximately 1.0 and the transmission coefficient and reflection coefficient being respectively 0.5 and 0.5 for the single reflection configuration and .66 and .33 for the dual reflection configuration.

29.   (New) An optical block in accordance with claim 20, including a lightguide or optical fibre associated with said input portion.

30.   (New) A Fourier Transform Spectrometer comprising an optical block as claimed in claim 20,, a light source for directing light to be interferometrically analysed to the input portion of said block so that the light beams incident on the reflectors and the beam splitter/combiner do not overlap, and a light sensor array for detecting the pattern of the fringe field, the fringe field having a multiplicity of fringes about a zero order fringe so that a Fourier transform of said fringe pattern corresponds to the spectral distribution of the illumination source.

31.   (New) A spectrometer according to claim 30, comprising a lens system adapted to form an image of the optimum contrast fringe field as localised on a plane relative to the inteferometer onto said sensor array, and wherein said sensor array comprising is a pixellated semi-conductor array.

32.   (New) A spectrometer according to claim 31, and including electronic processor adapted to generate the Fourier transform of the electrical signal generated by said array so as to measure the spectral distribution of the input light.

33.   (New) A spectrometer according to claim 30, comprising means for coupling light to and from the measurement zone, imaging light into interferometer and imaging the fringe field light out of optical block onto the detector array form an integral element of the interferometer.

34.   (New) A spectrometer according to any one of claims 30-33, and comprising a plurality of light sources each associated with an optical fibre, and wherein each optical fibre is adapted to direct light from its associated light source either onto or through a test medium, and wherein light reflected by, scattered from or transmitted through the test medium is, in operation of the spectrometer, coupled to said light sensor.

35.   (New) A spectrometer according to claim 30, wherein the spectrometer includes means whereby the light sources can be illuminated at different intervals.

36.   (New) A spectrometer according to any one of claim 30, in combination with a remote sensor.

37.   (New) A spectrometer according to claim 36, wherein the remote sensor is adapted to receive light from a coherence source through a semi-reflective mirror and includes means for separating light received from the coherence light source into two paths the lengths of which differ by a distance greater than the coherence length of the coherence light source.

38.   (New) A spectrometer according to claim 37, wherein the sensing head comprises a beam splitter, a fixed reference mirror and a movable mirror the position of which changes in response to a measurand.

39.   (New) A method of manufacturing an interferometric optical block having three planar nominally parallel surfaces with the two outer surfaces adapted to act as beam reflectors for internal light and the third surface in operation acting as a beam splitter and beam combiner, the optical block having an input portion by means of which an input beam of light to be analysed can be input so as partially to pass through said third surface to be internally reflected by one of said outer reflectors, and partially to be reflected by said third surface so as then to be internally reflected by the other of said outer reflectors whereby light internally reflected by said outer reflectors is combined at said third surface to produce an exit beam, and wherein said outer surfaces have an inclination with respect to one another and are asymmetric with respect to said third surface so as to generate in the exit beam a linear fringe field distributed about the zero-order fringe comprising cutting a single wedge element parallel to the wedge section to create two identical wedges and with one such wedge so cut rotated 180°, the lower face of said one wedge being secured to the other wedge to form a monolithic element which provides said optical block, the adjacent faces of the wedges forming said third surface.

REMARKS

Claims 20-39 are currently pending. These claims have been amended to conform them to U.S. practice and to eliminate unacceptable multiple claims dependency. No new matter has been introduced by these amendments.

The examiner is respectfully requested to consider the above preliminary amendment prior to examination of the application. If there are fees due in connection with the filing of this Preliminary Amendment, please charge the fees to Deposit Account No. 06-0916.

Respectfully submitted,

FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: January 25, 2002

By: _____
Ernest F. Chapman
Reg. No. 25,961

EFC/FPD/sci

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FOURIER TRANSFORM SPECTROMETER USING AN OPTICAL BLOCK

The present invention concerns interferometers and is particularly concerned with Fourier transform spectrometers. Fourier transform spectroscopy is a well known technique for obtaining the spectra of weak extended sources. It offers throughput and multiplex advantages which can give rise to superior signal-to-noise performance when compared to other methods.

As a result there has been an increasing demand for Fourier transform spectrometers over a wide range of applications including industrial, medical, environmental and consumer applications.

Accordingly there has been a trend of simplifying and ruggidising spectrometer instrumentation to enable it to be used in an extended range of applications. There is however a trade-off between performance and cost associated which tends to limit the range of applications of emerging products.

The present invention is particularly concerned with providing an extremely simple and robust component for a spectrometer as well as improved Fourier Transform Spectrometers.

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In one aspect the invention provides optical block in which light to be analysed is internally reflected and combined to produce an interference fringe pattern which can be measured to provide a spectral analysis of the

5   light.

In order that the invention may be more readily understood embodiments thereof, and of the prior art, will now be described by way of example and with reference to the accompanying drawings in which:

10   Figure 1 is a schematic view of a known Michelson interferometer;

Figures 2A and 2B show respectively a fringe function and a spectrum;

Figure 3 is a schematic diagram of another known

15   form of interferometer;

Figure 4 shows the basic component of an optical block in accordance with a first embodiment of the present invention;

Figure 5 is similar to Figure 4;

20   Figure 6A and 6B shows steps in the manufacture of the optical block of Figure 5;

Figure 7 is an illustration of a second embodiment

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of an optical block in accordance with the present invention;

Figure 8 is similar to Figure 7;

Figure 9 is similar to Figure 8 but has certain dimensions exaggerated in the interest of clarity;

Figure 10 is a diagram showing another embodiment of an optical block;

Figure 11 is a diagram illustrating a particular practical realisation of an embodiment of an optical block in accordance with the present invention;

Figure 12 is a diagram showing another practical implementation of an optical block in accordance with the present invention;

Figure 13 is a diagram illustrating a third practical implementation of an optical block in accordance with the present invention;

Figure 14 is a diagram of spectrometer according to the present invention;

Figure 15 shows two spectral waveforms;

Figure 16 is a diagrammatic perspective view of a practical embodiment of a spectrometer;

Figure 17 is a diagrammatic representation of a

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variant of the spectrometer of Figure 16;

Figure 18 is a similar view of another variant; and

Figure 19 is a diagram of a particular use of a spectrometer in accordance with the present invention.

Referring now to Figure 1 this shows the conventional form of an instrument based on a Michelson interferometer. In this arrangement the interference fringe field formed due to the superposition of the light field U_1 and U_2 reflected respectively from the mirrors M_1 and M_2 via the beam splitter B is incident on a light sensitive detector P. The aperture of this detector is made considerably smaller than the fringe spacing in the plane of detection. The output of this detector thereby defines the interference fringe intensity distribution generated as the mirror M_2 is translated. In Fourier transform spectroscopy this translation is arranged to occur over a distance $\pm$ D about the point where the path length in the translated arm of the interferometer l_2, matches that of the other arm, l_1. Figure 2 shows the form of the fringe envelope observed under these conditions where i (τ) is photo current of the detector P as a function of the mirror displacement $\pm$ D. Note

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that i (τ) is proportional to the interference fringe

pattern
$$I_{12} = I_1 + I_2 \times 2\sqrt{I_1 I_2}\,\gamma(\tau)\frac{4\Pi D}{\lambda} \qquad (1)$$

where

I$_1$ =   intensity of interfering beam U$_1$

I$_2$ =   intensity of interfering beam U$_2$

γ(τ)   =   coherence function of source

τ   =   D/C

λ   =   wavelength at light

c   =   speed of light

γ(τ) is equal to the correlation of the two beams of

light with a relative delay time τ = D/c i.e.

$$\gamma(\tau) = f(t)f^*(t+\tau)/\overline{|f(t)|^2} \qquad (2)$$

Where

f(t) = defines interfering waveform as function of time,

t.

By the Wiener-Khinchin theory, the Fourier transform

of γ(τ) is equivalent to the spectral intensity I(ω).

Hence the Fourier transform of the fringe function

generated in the specific way described provides a

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measure of the spectral distribution of the input light field as is shown schematically in Figure 2. It may be shown that the resolution of this type of spectrometer is given by

$$\left(\frac{\delta\lambda}{\lambda}\right)_{min} = \frac{\lambda}{2D_{max}} \qquad (3)$$

where D_{max} = maximum amplitude of mirror displacement

Hence a value of $D = 100\mu m$ will generate a wavelength resolution of under 1nm for $\lambda = 500nm$.

In practice the translation mechanism has to be extremely precise in order to minimise variations in the fringe spacing and vibration across the detector since such variations also cause a modulation of the fringe envelope and introduce errors in the resultant spectrum. This problem is usually minimized by the use of corner cube reflectors but nonetheless these are expensive the instrument still requires a precision positional encoder to define the transform time scale (D/c).

Moving parts can be eliminated by using the arrangement shown in Figure 3 in which the mirror M_2 is rotated by an angle ε about an axis co-incident with the zero-order fringe. A distributed fringe field is then

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observed which is imaged in the plane of a pixellated

detector array DA by the lens L. The fringe field

envelope is then defined by the spatially scanned output

of the detector array and is equivalent of that shown in

5   Figure 2 but does not require the translation of a

mirror.

Various configurations of interferometer are

described in the prior art which are aimed at simplifying

and ruggedising the extended fringe field interferometer

10   described above. These include the use of a

polarising/birefringent elements to reduce the system to

a common path interferometer and a common path, contra

propagating three element Sagnac configuration.

Referring now to Figure 4 of the drawings this shows

15   an optical block which comprises two optical elements 1

and 2 which may be fabricated from conventional good

quality optical materials such as BK7 glass. The term

optical block is used to define the optical components in

which the interference fringe field is actually

20   generated.

The optical block shown in Figure 4 has a common

central element BS/C which acts as a beam splitter and

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combiner and is placed between reflectors R_1 and R_2. The planes of R_2, BS/C and R_1 are nominally parallel and R_1 and R_2 separated by a distance of respectively S_1 and S_2 from BS/C. An input beam U_1 of diameter a_i is incident

5   at angle θ to the surface normal of BS/C such that adjacent beams incident on R_1 and R_2 do not overlap. This requires that $\theta > \sin^{-1} 2S_{1,2}/a_i$. Under these conditions it can be seen that two beam interference will occur between various combinations of beam propagating through and

10   exiting from the R_1, R_2 BS/C structure (e.g. at d and f).

In the embodiment shown in Figure 4 the interfering beams are reflected once from the outer reflectors. The input beam is split at BS/C into the reflected and transmitted components U_r, U_t respectively. These are in

15   turn reflected from R_1 and R_2 and recombine at B/SC. The interferogram described by equation 1 is generated by arranging for the faces R_1 and R_2 to be inclined at a total angle ε with respect to one another. This is more clearly shown in Figure 5 whilst ensuring that the zero

20   order fringe for which $S_1 = S_2$ is nominally at the centre of the fringe field. The fringes will localise i.e. have maximum contrast in the plane which the interfering beams

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intersect as shown in Figure 5. In practice a lens is used to form an image of the localised fringe field in the plane of the detector array.

A preferred embodiment of this interferometer may be fabricated from a single wedge cut into two wedges along the wedge section as shown in Figure 6. One wedge is then rotated in its plane by 180°C about the cut orientation and its lower face cemented to that of the other prism to form the monolithic element or optical block shown. An input beam 3, output lens 4 and sensor array 5 are also shown. In order to maximise the optical throughput the reflection coefficients of R_1 and R_2 should be as near 1.0 as possible and transmission (t) of reflection (r) coefficients of BS/C should both be equal to 0.5. The sensor array may be any suitable pixellated semiconductor array such as a CCD array.

A key objective in fabrication is to maintain repeatability of fringe geometry. In the above configuration this will depend upon the extent to which the wedge alignment and attachment process causes variations of the orientation of R_1 and R_2 relative to the reference wedge angle $\varepsilon/2$. Sensitivity to alignment

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tolerance is relaxed relative to for interferometric

precision required in the latter case when the number of

reflections at R_1 and R_2 is extended from 1 to 2 as shown

in Figure 7. Under these conditions the interfering

5   beams are common to R_1 and R_2 and relative misorientation

of the latter do not therefore effect the fringe spacing.

An angular separation between the interfering beams

in this dual reflection geometry is formed either by

tilting one or a combination of the section of each

10   reflector upon which an individual beam is incident. If

the sections A,B,C,D of the reflectors shown in Figure 8

delineate the regions over which there is no overlap of

the incident beams they therefore define the sections

that may be tilted relative to one another.

15   Figures 9 and 10 show respectively the arrangement

in which section A and sections A&B are tilted. Here it

will be noted that the only requirement when two sections

are tilted is that the tilts be in an opposite sense so

that the angular displacement created by the first is not

20   compensated by the second. The position of the zero

order fringe will also be a function of the relative tilt

of the two reflectors since this will define the point

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for which the path lengths of the two interfering beams
are equal. In the case of Figure 9 (A tilted only) the
zero fringe will occur at the extreme edge of the
interference field. This position will shift towards the
5   centre as B is tilted in the opposite sense (Figure 10)
and will be at the centre of the fringe field when the
tilts of the two mirrors are equal. Note that a lateral
shift of the dual angle reflector relative to the flat
provides a means of fine tuning the position of the zero
10   order fringe.

For one class of preferred configuration the tilts
are confined to the R_1 element so that the BS/C and R_2
functions may be combined on a single optical flat with
parallel faces. Figure 11 illustrates how the optical
15   block is formed by such an optical flat located on an
element M which incorporate the symmetrically tilted
reflector R_1. In practice M could be a precision moulded
component and the optical block assembled by inserting
the flat F in the pre-moulded location. This procedure
20   is compatible with low cost components and manufacture
since as has been noted above, this configuration of the
optical block is not dependent on the precision location

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of R_1 with respect to R_2.

Figure 11 also shows the additional components the system consisting of an extended source S (which may in practice consist at a large core optical fibre),

5   collimating/focussing input lens L_1, output fringe and field imaging element L_o and detector array A. These elements will, in general, be required for all geometrics at the interferometer.

Figure 12 shows an alternative way of manufacturing

10   the optical block in which the optical flat G is attached directly to the dual angle prism H. This arrangement is particularly robust and could, for example, be manufactured from low expansion glass to enable operation at elevated temperatures. Figure 12 shows the same basic

15   design in which all faces are mutually tilted. This configuration could be manufactured by slicing and rejoining a dual angle prism in accordance with the principle indicated in Figure 7 for a single angle (i.e. wedge) prism.

20   In order to maximise the optical throughput the outer reflection R_1 and R_2 should have a coefficient of reflectivity as near to unity as possible and the

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reflection (r) and transmission coefficients r,t at BS/C

should be respectively .33 and .66. These coefficients

should apply over the spectral range of operation.

Figure 14 shows schematically a typical practical

5   implementation of the optical blocks just described in an

interferometer. Here light from a source S is coupled to

a region of test T via a beam splitter B.

In this configuration T may be a sample for which it

is required to measure the spectral reflectivity.

10   Alternatively T may be a passive reflector and the

spectral transmission of the medium between the light

delivery element and T measured. In either case light is

coupled into the interferometer I via the current lens L_i

and imaged onto the detection array DA by the output lens

15   L_o. In a preferred configuration all of the elements

external to the interferometer may in practice be

integrated with the structure at the optical block of the

interferometer by combining, for example, moulded light

guides and lenses with the reflective elements.   The

20   output of the detection array can be Fourier transform

analysed in a well known manner by a suitable processor

PC for display or printing.

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Figure 15 is an example of a preliminary experimental result which shows the spectrum of the same source measured using a calibrated spectrometer and that obtained using a laboratory version of the dual

5   reflection spectrometer described above.

It will be appreciated that the optical blocks just described are compatible with robust monolithic fabrication of the two elements. With respect to the current state of the art it therefore reduces cost by

10   eliminating the need for specialised components whilst simplifying manufacture by virtue of the reduction in component number.

Referring now to Figure 16 this shows a practical embodiment of an interferometer incorporating an optical

15   block of the type previously described. Thus a main housing 1 houses the optical block 2. An LED 3 supplies light of a predetermined wavelength to a optical fibre 4 which is bifurcated at 5 so as to direct light reflected from a test surface 6 onto a lens 7 which is arranged to

20   input the reflected light to the optical block 2. Light issuing from the optical block 2 is collected by a lens 8 and focussed onto a photosensitive array 9, for example

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composed of CCD sensors. A unit 10 houses power for the
LED and the CCD array and also provides in the form of a
microprocessor output signals for controlling the sensor
array in order to enable an output to be sent via an
5   output port 11 to a suitable processor 12 where the
results of the spectroscopy can be analysed and displayed
on the screen 13 of the processor.

As will be appreciated the entire arrangement of the
spectrometer can be encapsulated in a plastics material
10   so that the components are rigidly held in the correct
relationship and that the spectrometer is extremely
resistant to shock and other adverse conditions.

Turning now to Figure 17 of the accompanying
drawings, this discloses one particular way in which
15   spectrometers according to the present invention can be
utilised. It will be appreciated that Fourier transform
spectrometers do not require small input apertures as in
the case for disbursive grating devices for which narrow
input slips, typically less than 0.1mm are required.
20   With the embodiments described good results can be
achieved with 2mm diameter input fibre bundles. This
means that the embodiment shown in Figure 16 may be used

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to multiplex a number of light sources and points of measurement of the surface D into a single spectrometer. Thus in Figure 16 the single LED may be replaced by a number of separate light sources all under the control of

5   the microprocessor housed in unit 10. Similarly the optical fibre 4 is replaced by a plurality of parallel optical fibres each coupled to an individual light source and instead of a single output as shown in the figure, each of these light fibres have their outputs spread

10   across at least one dimension of the target surface 6. Similarly the input to the lens 7 would be from the bundle of fibres as bifurcated at 5.

       This arrangement is shown diagrammatically in Figure 17. In Figure 17 a number of light sources S1 to

15   Sn and an equivalent number of points of measurement of a surface D, P1 to Pn, are coupled to a single spectrometer. Here light from the sources is first coupled into the fibres F1 to Fn and then to directional 3dB (50:50) or bifurcated couplers C1 to Cn. The light

20   is then coupled out of the fibres onto the object D. The light scattered/reflected from the points of measurement P1 to Pn in the object is coupled to the spectrometer via

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the 3dB couplers and the output fibres F1 to Fn.   As
discussed S1 to Sn may be time multiplexed so that only
one measurement point P is illuminated at a given time.
Under these conditions a spectral image of the surface D
may be synthesised from the time demultiplexed output of
the spectrometer by the processor shown at 12.

The above arrangement can be configured in the
transmissive mode using the fibre arrangement shown in
Figure 17. A similar dual fibre arrangement can also be
used for reflective measurements.

Referring now to Figure 18 this shows an embodiment
in which a spectrometer in accordance with the present
invention is combined with a remote sensing head 20 of
rugged construction and receives light from a short
coherence source 21 through a semi-reflective mirror 22
and an optical fibre link 23. After reflection in the
sensing head 20 light is returned through the optical
fibre link 23 to the mirror 22 and reflected into a
Fourier transform spectrometer which can be identical to
the spectrometer shown in Figure 16 and which is,
therefore, in accordance with the present invention.

The purpose of the arrangement shown in Figure 18 is

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to separate the sensing head from the processing interferometer and to provide a sensing head which does not contain any active optical or electronic components but contains only passive optical elements which may accordingly be highly resistant to hostile environments. Thus the sensing head 20 comprises a beam splitter 25, a fixed reference mirror 26 and a movable mirror 214, the position of which changes in response to the measureand. The optical path lengths between the beam splitter 25 and the mirrors 26 and 27 are arranged to be different and the difference between these two path lengths is arranged to be substantially greater than the coherence length of source 21. As a result of this when the light reflected by the two mirrors 26 and 27 is recombined in the beam splitter 25, interference fringes will not be apparent in the combined beam supplied back to the optical fibre link 23. Thus the spectrometer 24 is arranged to compensate for the path length difference introduced in the remote sensing head 20 and generate a fringe field for which absolute phase changes occurring at the sensor can be determined.

It will be appreciated that as with the embodiment

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previously described a plurality of remote sensing heads

can be used each associated with an individual coherent

light source and the outputs of the various sensing heads

combined into an optical fibre bundle for transmission to

5   the Fourier transform spectrometer 24. Once again it is

possible to control the lighting pattern of the coherent

light sources so that the signals received by the

spectrometer from the light sources and sensing heads are

temporarily spaced for subsequent analysis by a computer

10   system similar to that shown in Figure 16.

It is of course possible that either an optical

block similar to any one of those described in the

preceding specification could be employed in the remote

sensing head or heads of the embodiment just described.

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CLAIMS:

1. An interferometric optical block having three planar
nominally parallel surfaces with the two outer surfaces
5   adapted to act as beam reflectors for internal light and
the third surface in operation acting as a beam splitter
and beam combiner, the optical block having an input
portion by means of which an input beam of light to be
analysed can be input so as partially to pass through
10 said third surface to be internally reflected by one of
said outer reflectors, and partially to be reflected by
said third surface so as then to be internally reflected
by the other of said outer reflectors whereby light
internally reflected by said outer reflectors is combined
15 at said third surface to produce an exit beam, and
wherein said outer surfaces have an inclination with
respect to one another and are asymmetric with respect
to said third surface so as to generate in the exit beam
a linear fringe field distributed about the zero-order
20 fringe.

2. An optical block in accordance with claim 1 in which
the exit beam results from the interference of the beams
transmitted and reflected from the beam splitter/combiner

25

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that have in operation each undergone a single reflection

at the outer reflectors.

3. An optical block in accordance with claims 1 or 2

5   which has been fabricated by cutting a single wedge

element parallel to the wedge section to create two

identical wedges and with one such wedge so cut rotated

180°, the lower face of said one wedge being secured to

the other wedge to form a monolithic element, the

10   adjacent faces of the wedges forming said third surface.

4. An optical block in accordance with claim 1 in which

the exit beam in operation results from the interference

of beams combined at the beam splitter/combiner which

15   have undergone two reflections at the outer reflectors.

5. An optical block in accordance with any preceding

claim in which the beam splitter/combiner and one

reflector are formed by an optical flat with parallel

20   faces and the other reflector is provided by a single

unit comprising the inclined mirror or mirrors and an

integral location for the optical flat.

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6. An optical block in accordance with any one of claims 1 to 4 in which the beam splitter/combiner and one reflector are formed by an optical flat with parallel faces and the other reflector by a solid prism with one plane face and an inclined second face, the block having been assembled by attaching the plane fact of the solid prism to the plane beam splitter/combiner face of the optical flat.

7. An optical block in accordance with any one of claims 1 and 4 fabricated from two identical solid dual angle prisms where the plane faces are attached to form the beam splitter combiner and the outer identical and mutually inclined faces form the reflectors.

8. An optical block in accordance with claim 7 in which the prisms have been obtained by cutting in two a single dual angle prism in a plane parallel to the dual angle section.

9.   An optical block according to any one of the preceding claims wherein in order to maximise optical

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throughput over the spectral range of operation said beam

splitter/combiner and reflector surfaces are coated with

a coating such that the reflectivity coefficient of the

reflectors is approximately 1.0 and the transmission

5   coefficient and reflection coefficient being respectively

0.5 and 0.5 for the single reflection configuration and

.66 and .33 for the dual reflection configuration.

10.   An optical block in accordance with any preceding

10   claim including a lightguide or optical fibre associated

with said input portion.

11.   A Fourier Transform Spectrometer comprising an

optical block as claimed in any one of the preceding

15   claims, a light source for directing light to be

interferometrically analysed to the input portion of said

block so that the light beams incident on the reflectors

and the beam splitter/combiner do not overlap, and a

light sensor array for detecting the pattern of the

20   fringe field, the fringe field having a multiplicity of

fringes about a zero order fringe so that a Fourier

transform of said fringe pattern corresponds to the

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spectral distribution of the illumination source.

12.   A spectrometer according to claim 11, comprising a lens system adapted to form an image of the optimum

5   contrast fringe field as localised on a plane relative to the inteferometer onto said sensor array, and wherein said sensor array comprising is a pixellated semi-conductor array.

10   13.   A spectrometer according to claim 12 and including electronic processor adapted to generate the Fourier transform of the electrical signal generated by said array so as to measure the spectral distribution of the input light.

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14.   A spectrometer according to any of claims 11 to 13 comprising means for coupling light to and from the measurement zone, imaging light into interferometer and imaging the fringe field light out of optical block onto

20   the detector array form an integral element of the interferometer.

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15. A spectrometer according to any one of claims 11 to 14, and comprising a plurality of light sources each associated with an optical fibre, and wherein each optical fibre is adapted to direct light from its associated light source either onto or through a test medium, and wherein light reflected by, scattered from or transmitted through the test medium is, in operation of the spectrometer, coupled to said light sensor.

16. A spectrometer according to claim 16, wherein the spectrometer includes means whereby the light sources can be illuminated at different intervals.

17. A spectrometer according to any one of claims 11 to 16, in combination with a remote sensor.

18. A spectrometer according to claim 17, wherein the remote sensor is adapted to receive light from a coherence source through a semi-reflective mirror and includes means for separating light received from the coherence light source into two paths the lengths of which differ by a distance greater than the coherence

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length of the coherence light source.

19.   A spectrometer according to claim 18, wherein the

sensing head comprises a beam splitter, a fixed reference

5   mirror and a movable mirror the position of which changes

in response to a measurand.

ABSTRACT

The invention concerns an interferometric optical block for Fourier Transform spectrometers having three planar nominally parallel surfaces with the two outer surfaces adapted to act as beam reflectors for internal light and the third surface in operation acting as a beam splitter and beam combiner, the optical block having an input portion by means of which an input beam of light to be analysed can be input so as partially to pass through said third surface to be internally reflected by one of said outer reflectors, and partially to be reflected by said third surface so as then to be internally reflected by the other of said outer reflectors whereby light internally reflected by said outer reflectors is combined at said third surface to produce an exit beam, and wherein said outer surfaces have an inclination with respect to one another so as to make a variation in path lengths in the light forming the exit beam so as to generate an interference fringe field.

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FIG. 1

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FIG. 2(B)

$I(\omega)$

$\left(\omega = \dfrac{2\pi c}{\lambda}\right)$

SPECTRUM

FT

$\dfrac{\text{FOURIER}}{\text{TRANSFORM}}$

FIG. 2(A)

$i(\tau) \propto I_{12}$

$\gamma(\tau)$

$\left(\tau = \dfrac{D}{c}\right)$

FRINGE FUNCTION

SUBSTITUTE SHEET (RULE 26)

FIG. 3

4/13
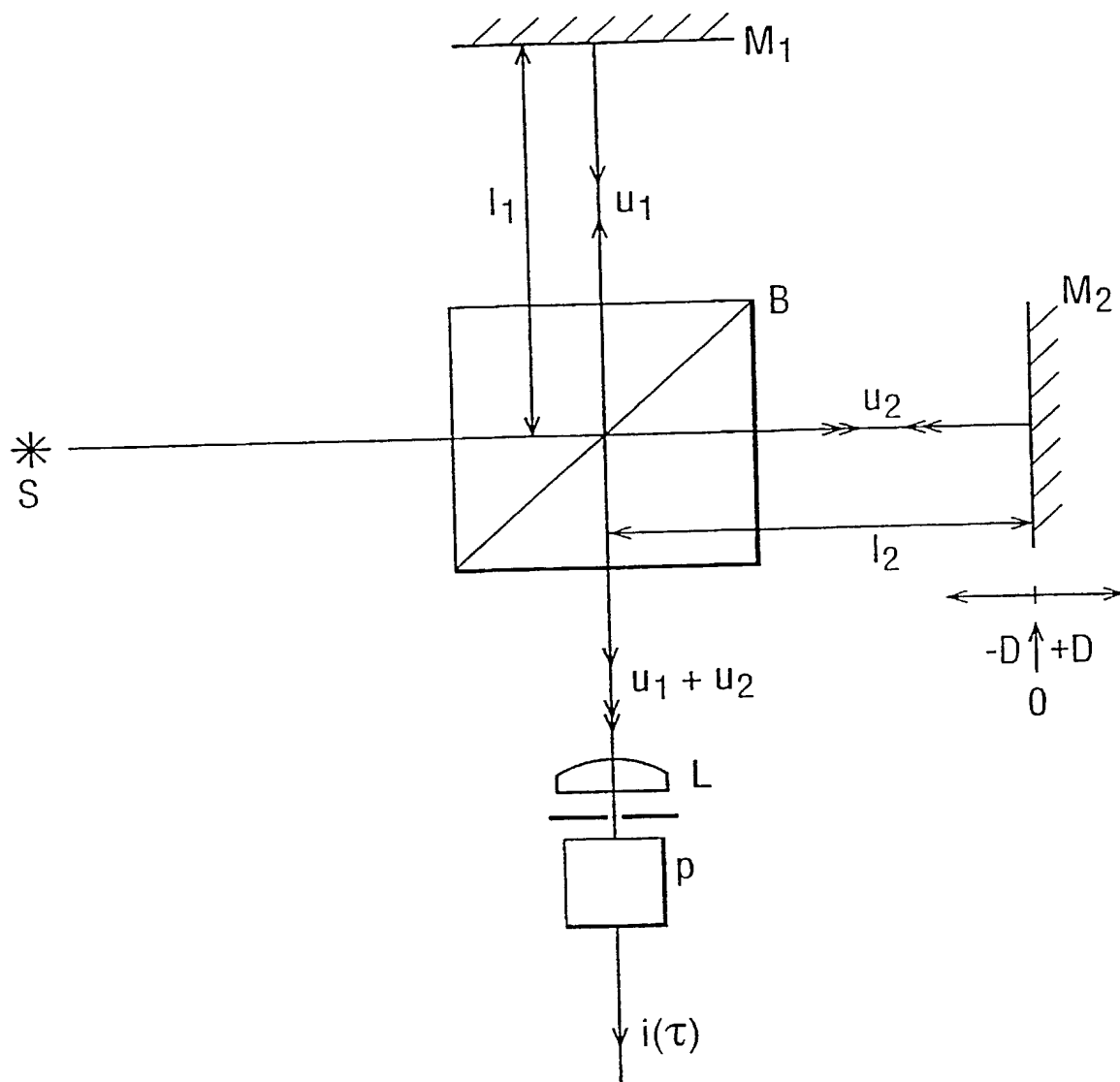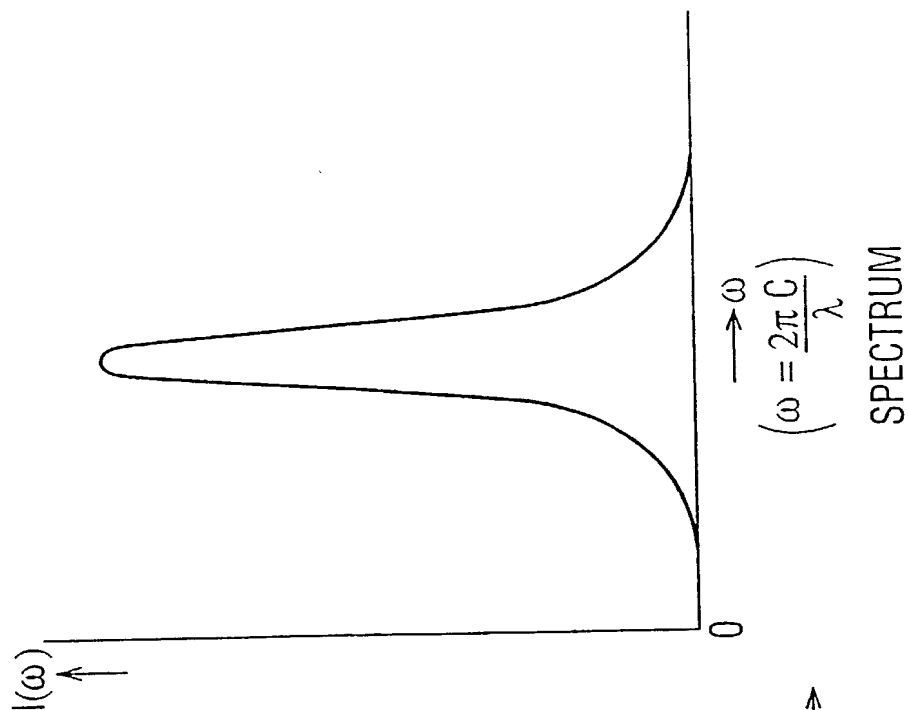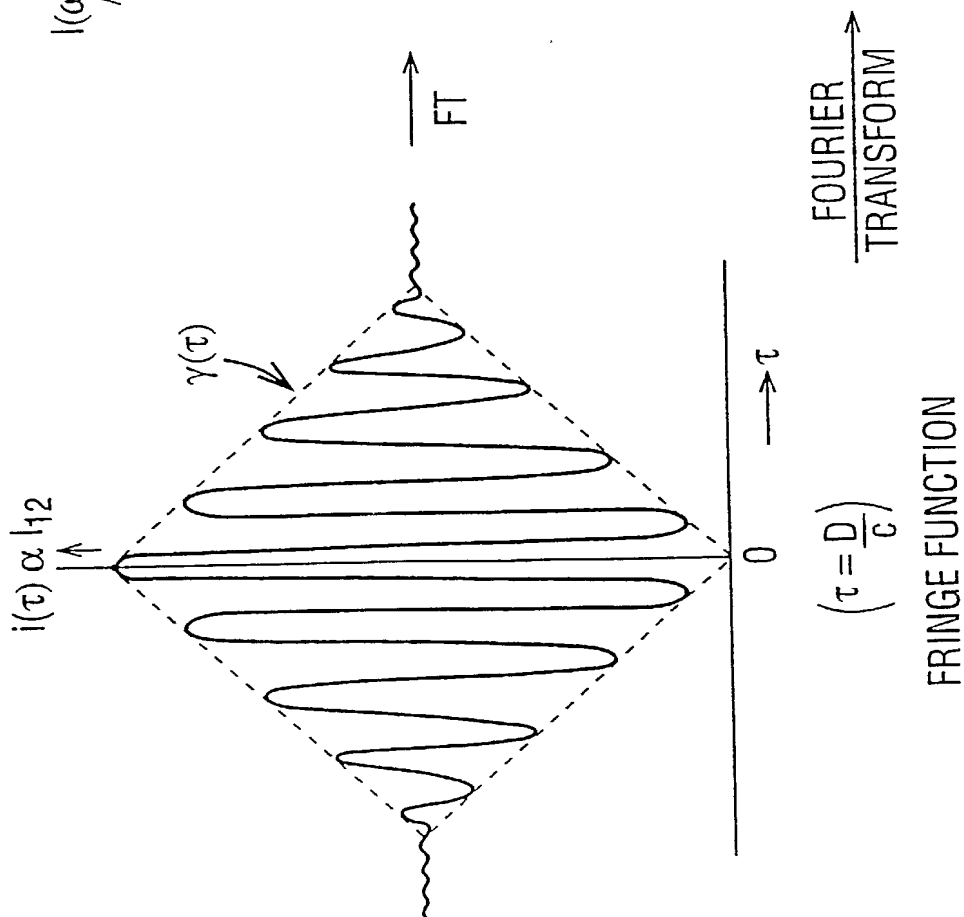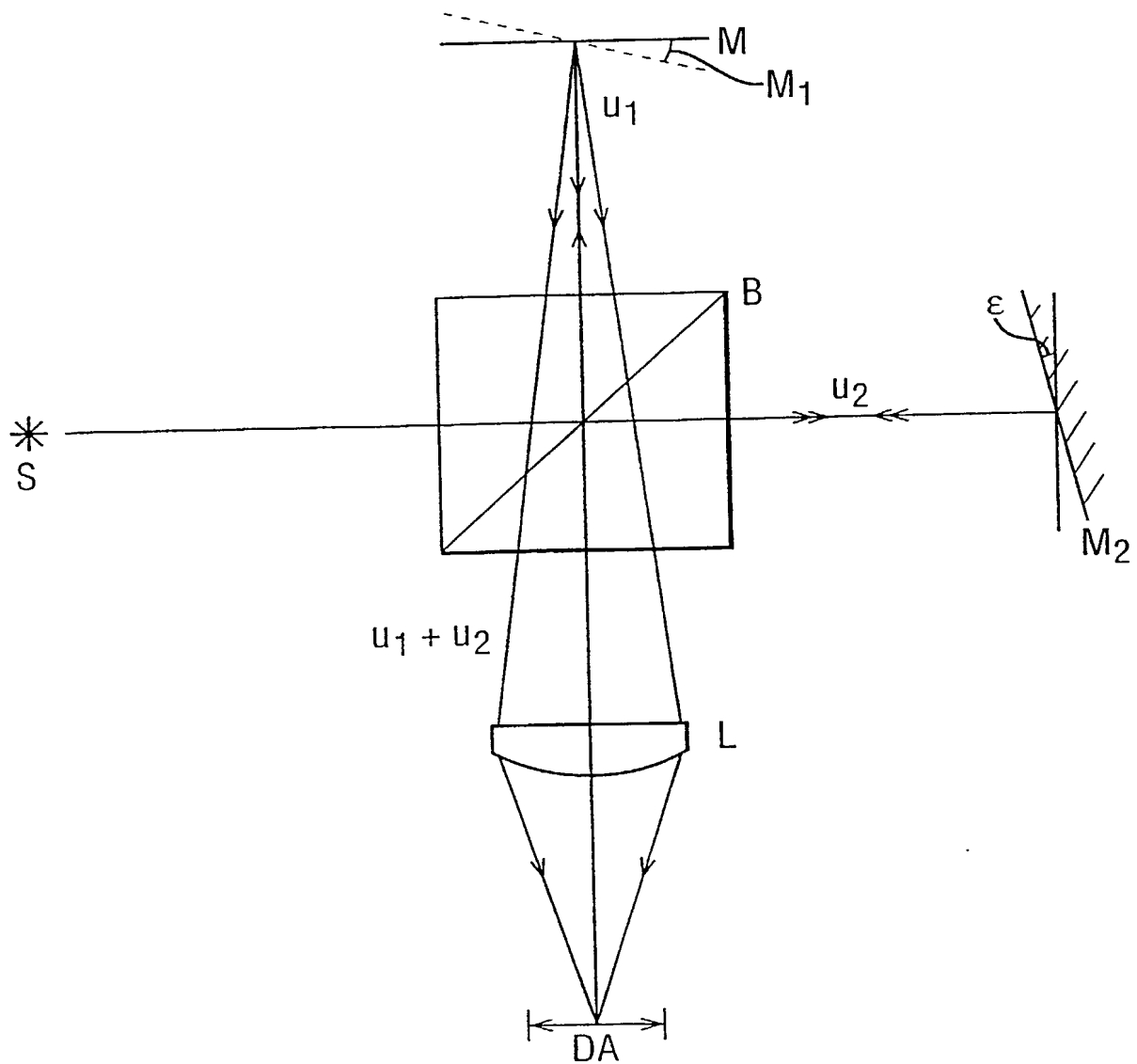
FIG. 4
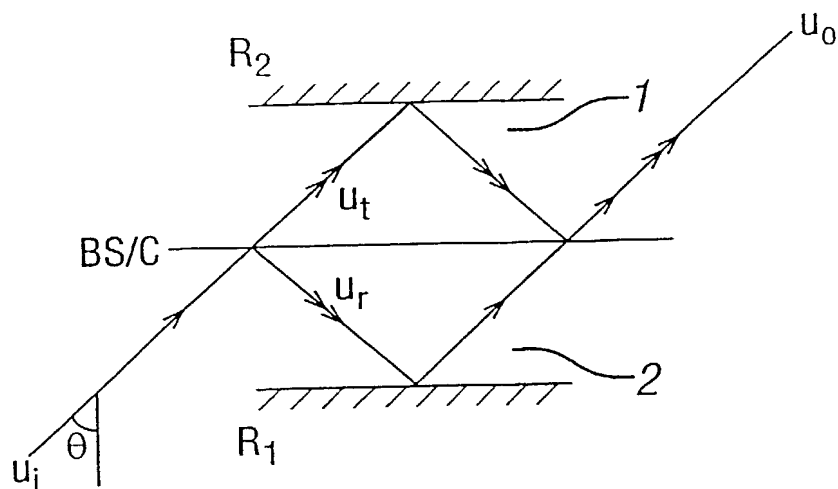
FIG. 5
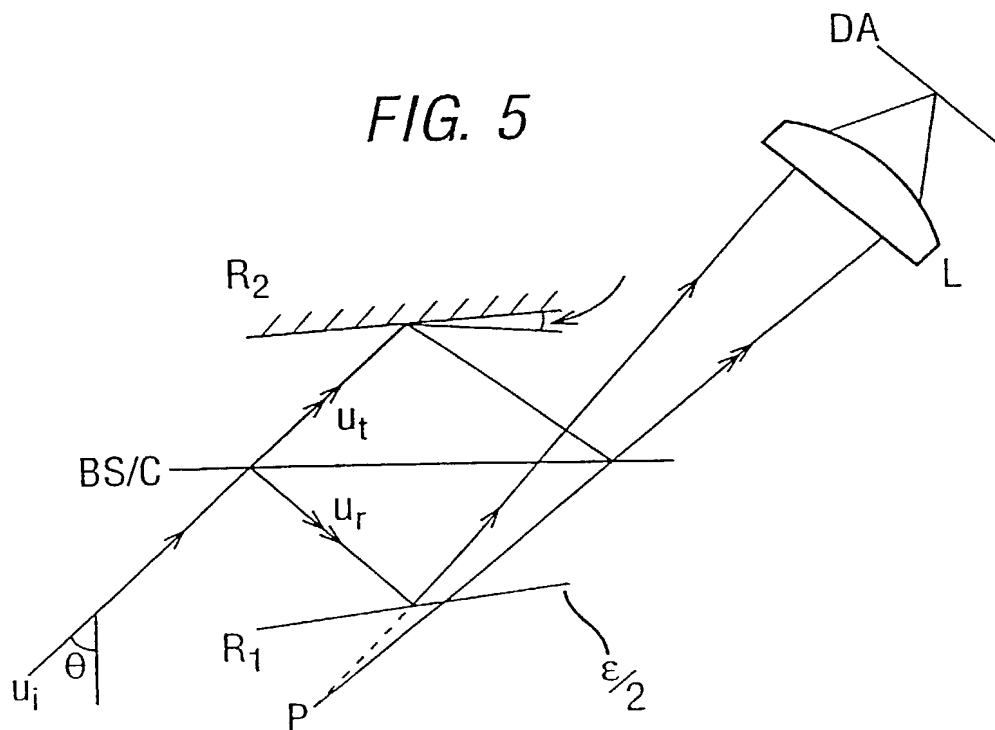
FIG. 6(A)
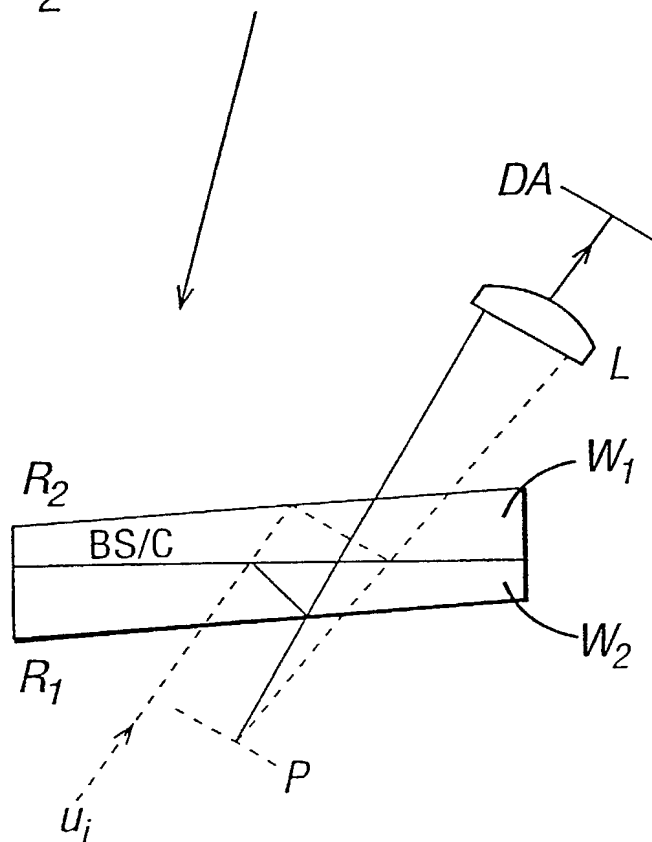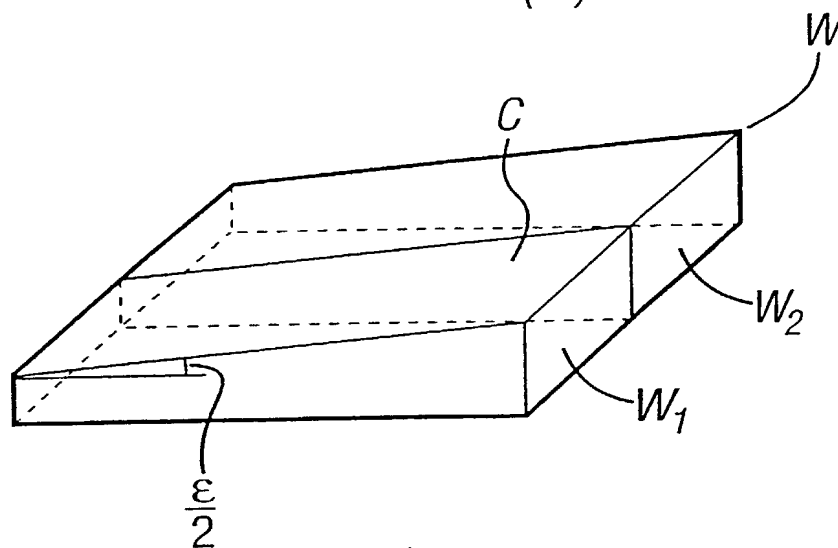
FIG. 6(B)

FIG. 7
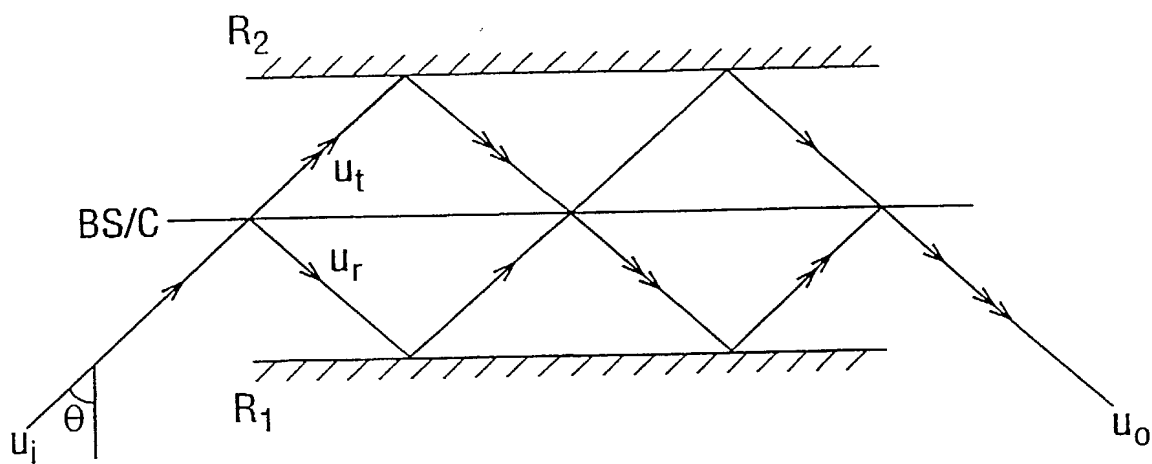
FIG. 8
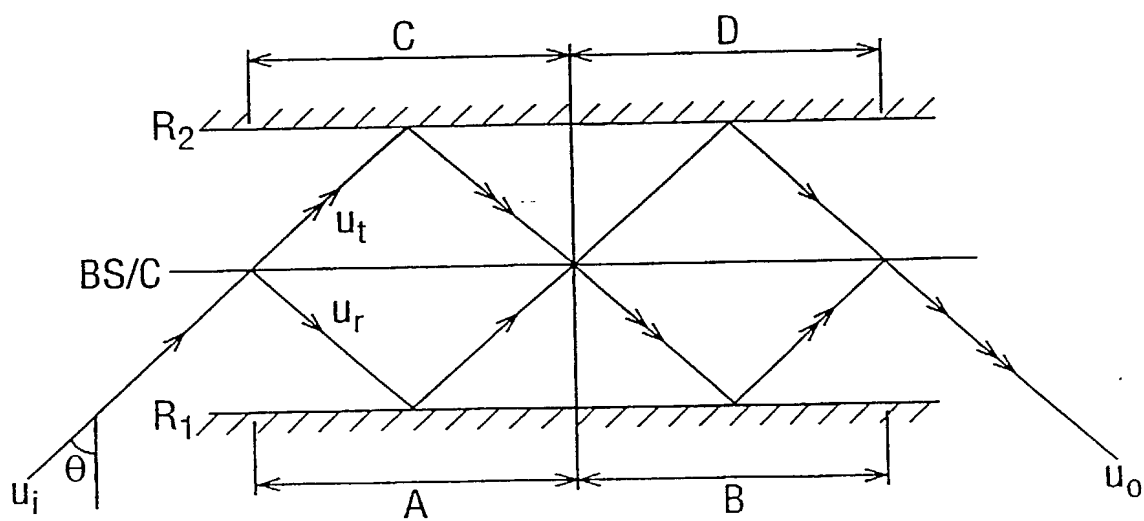
FIG. 9
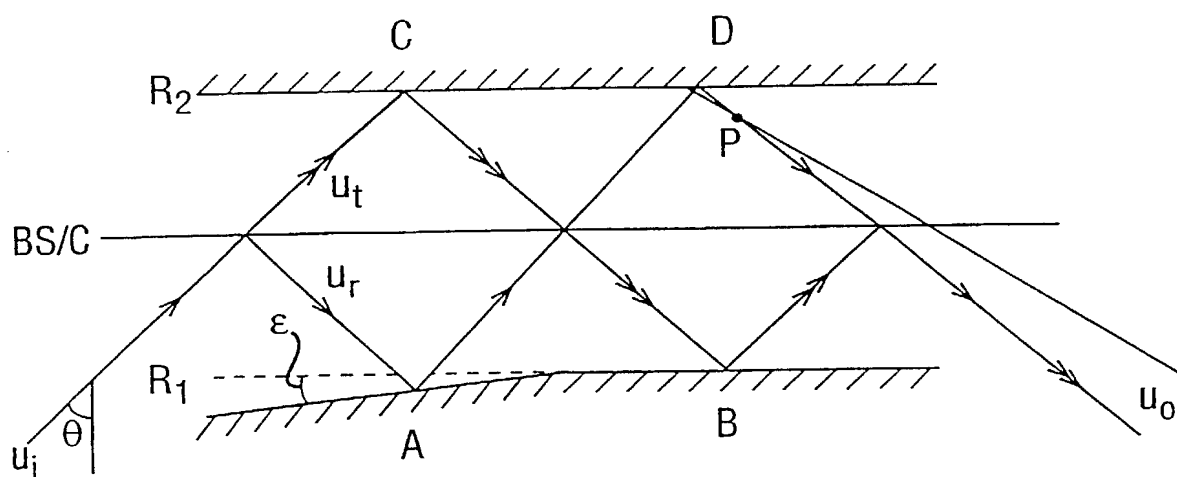
FIG. 10
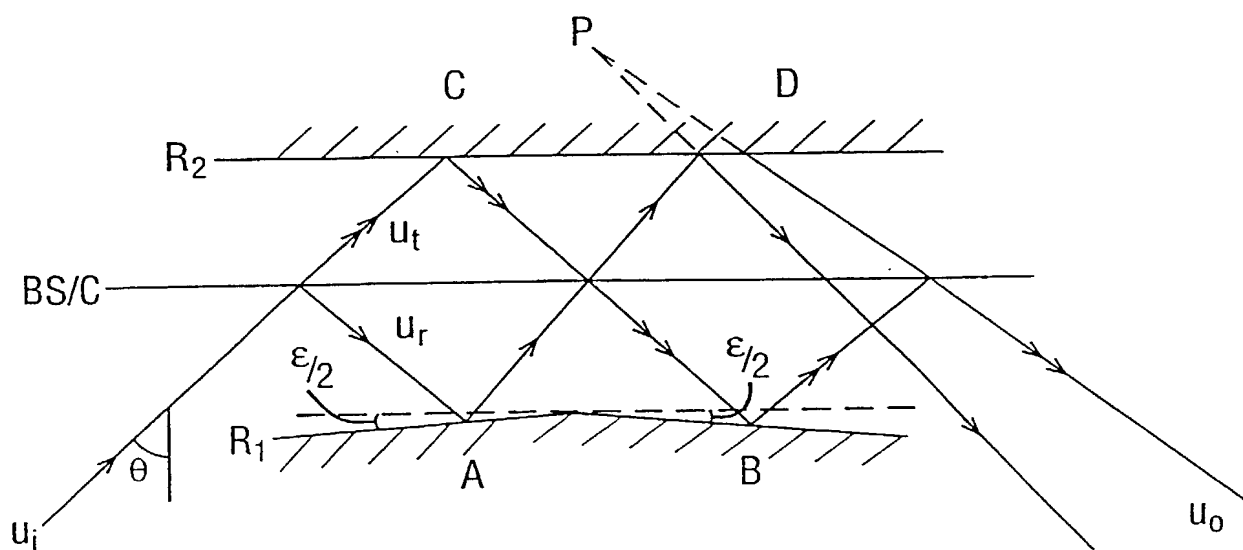
FIG. 11
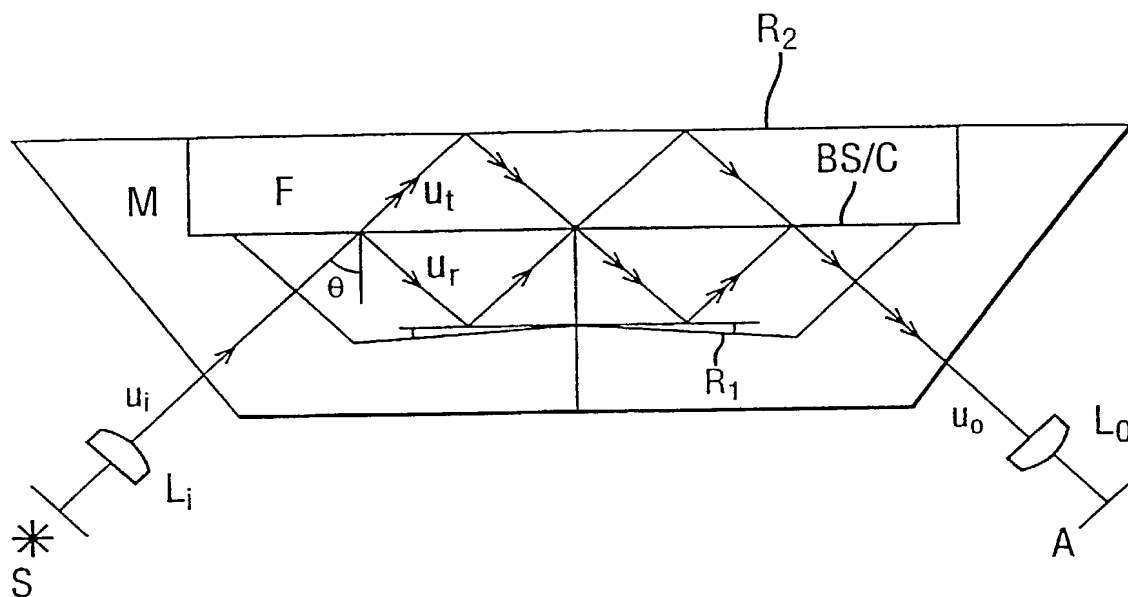
FIG. 12
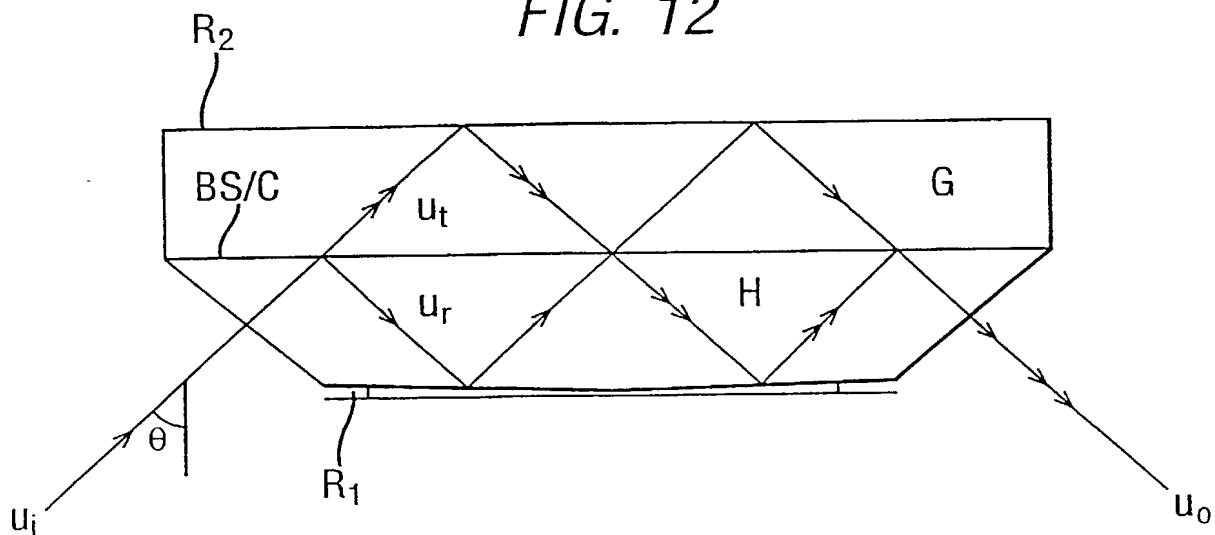
FIG. 13
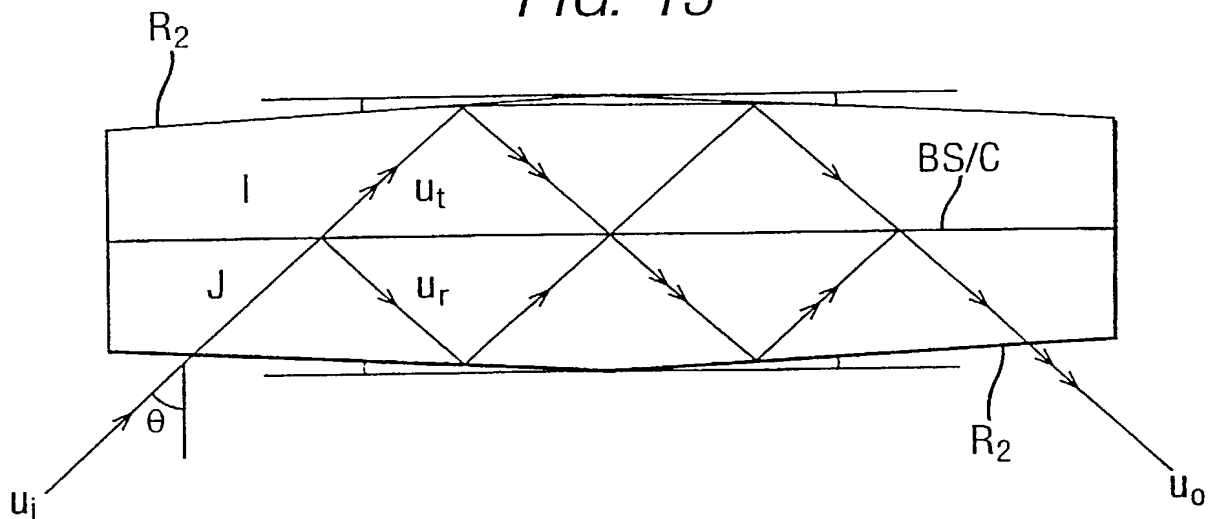
FIG. 14
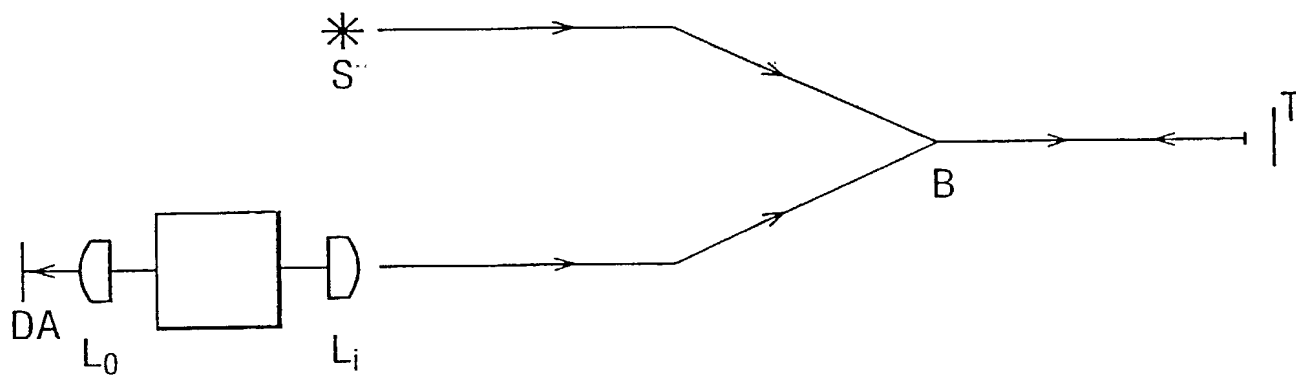
FIG. 15
ROYAL BLUE (FILTER 007)
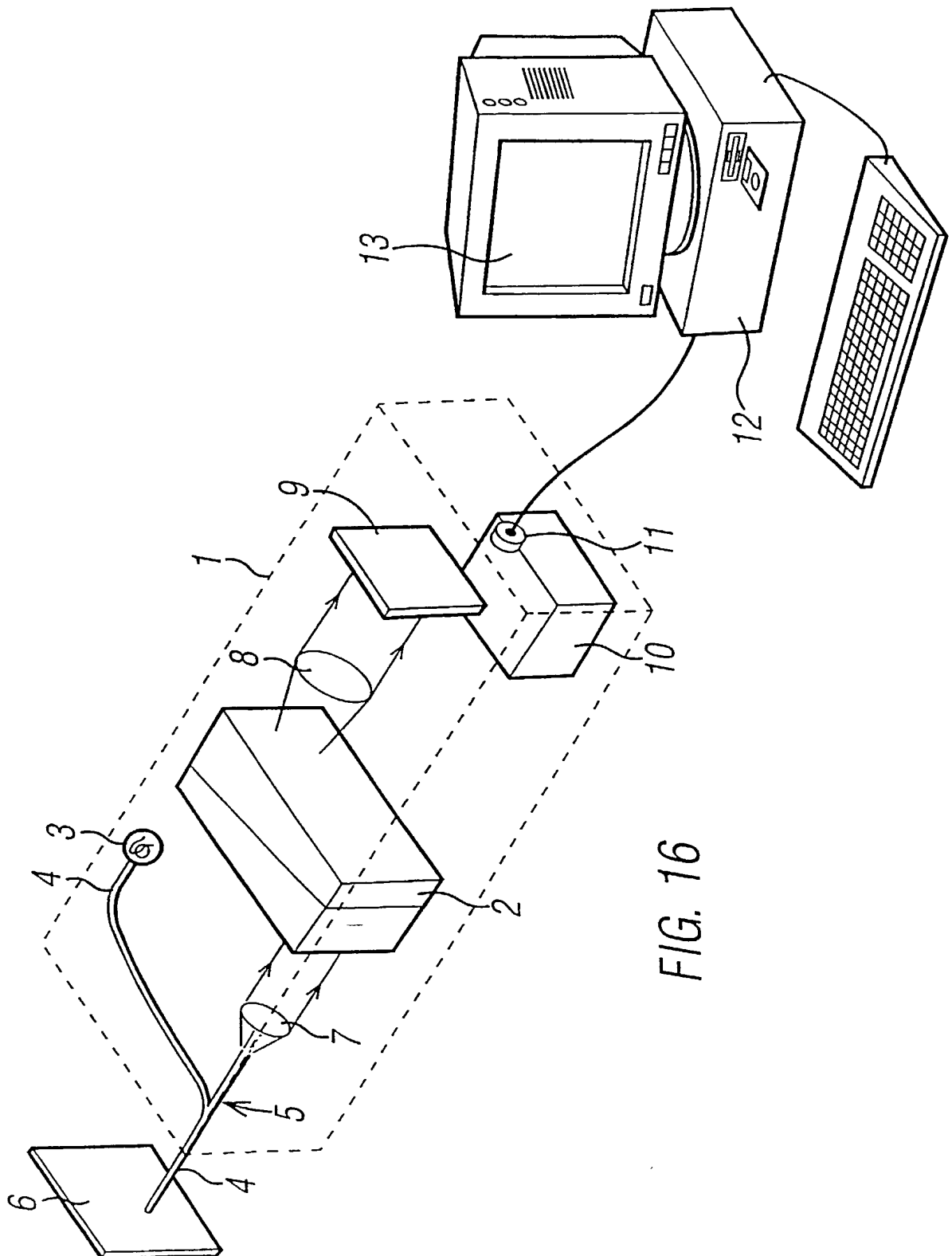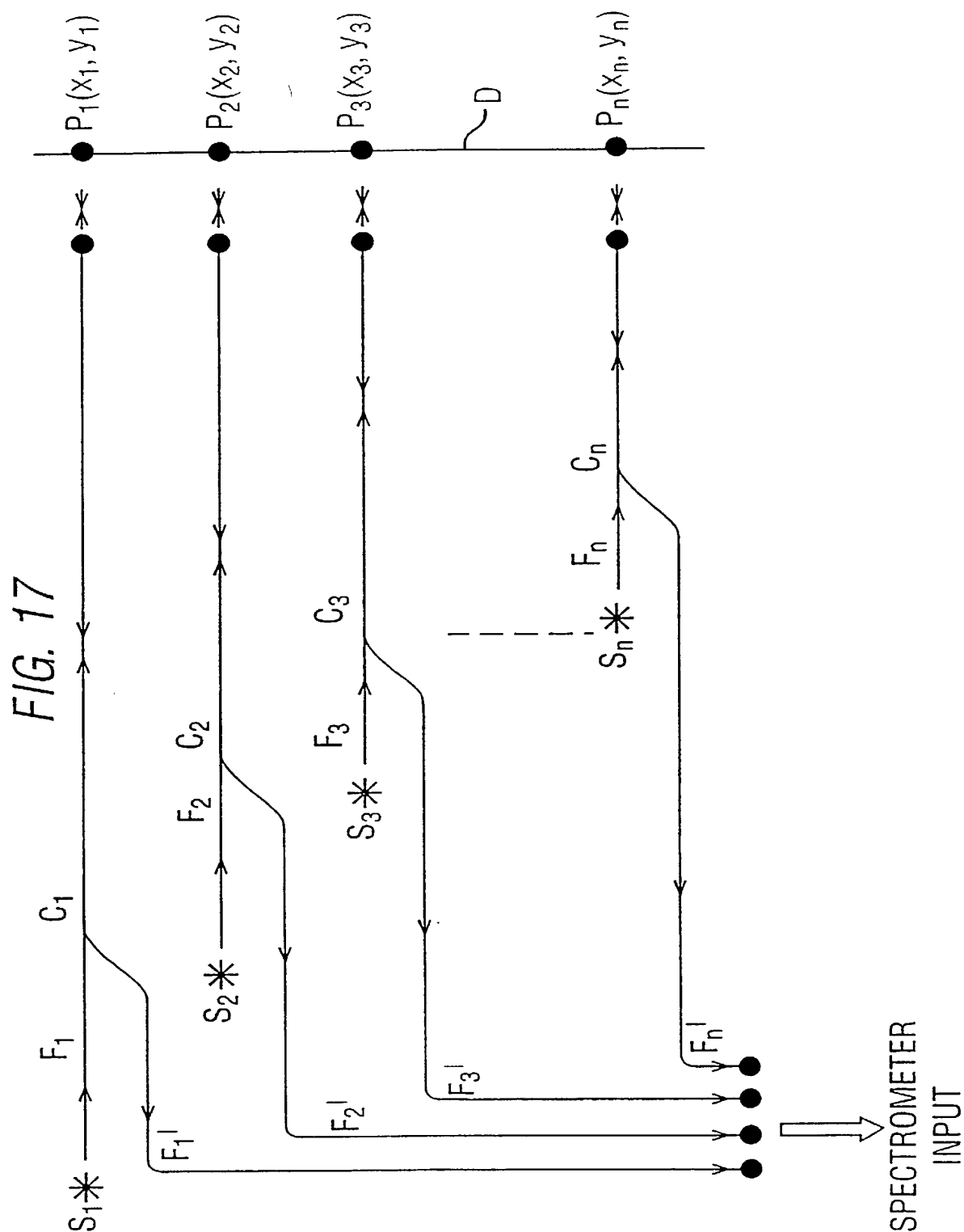
CALIBRATION
INTERFEROMETER

LAB RIG

FIG. 16
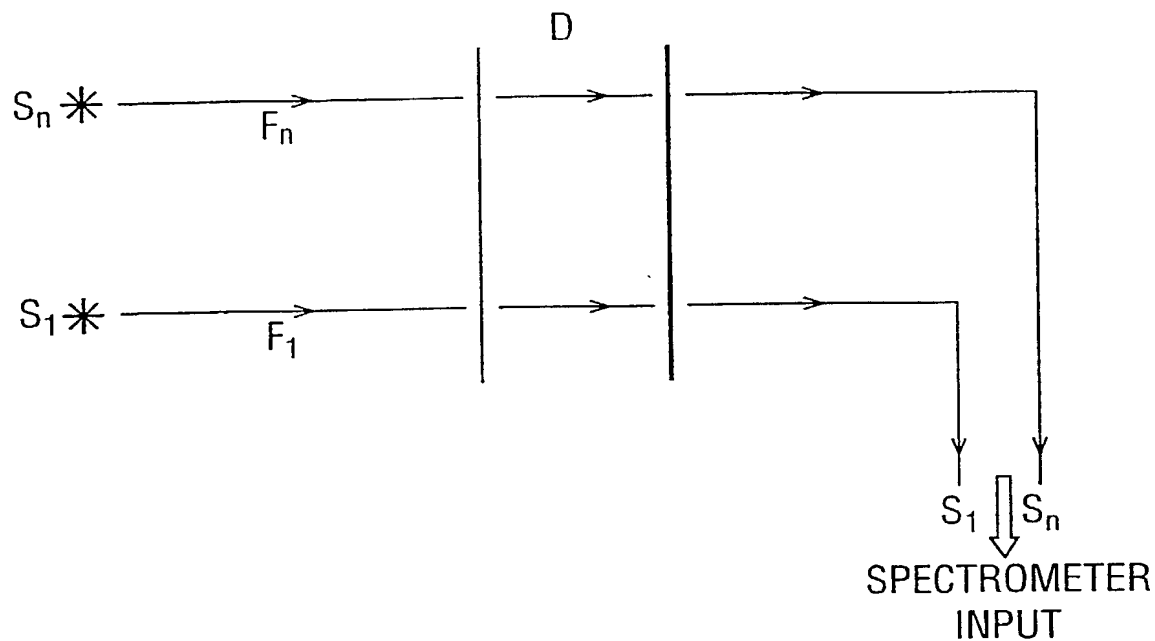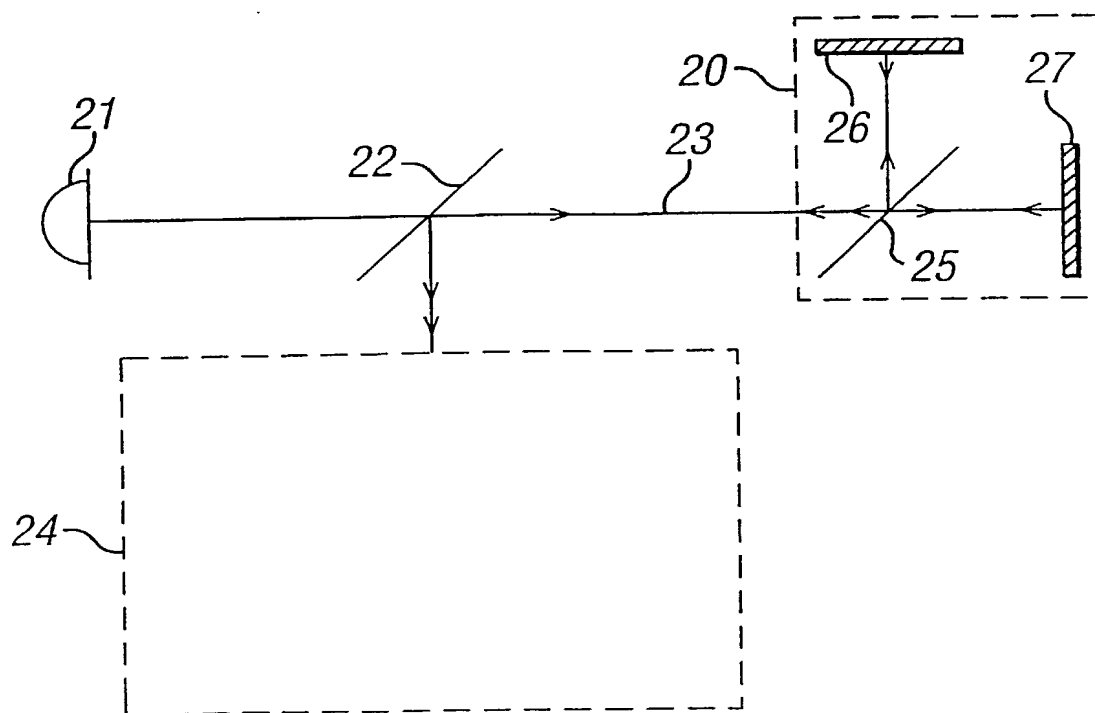
FIG. 17
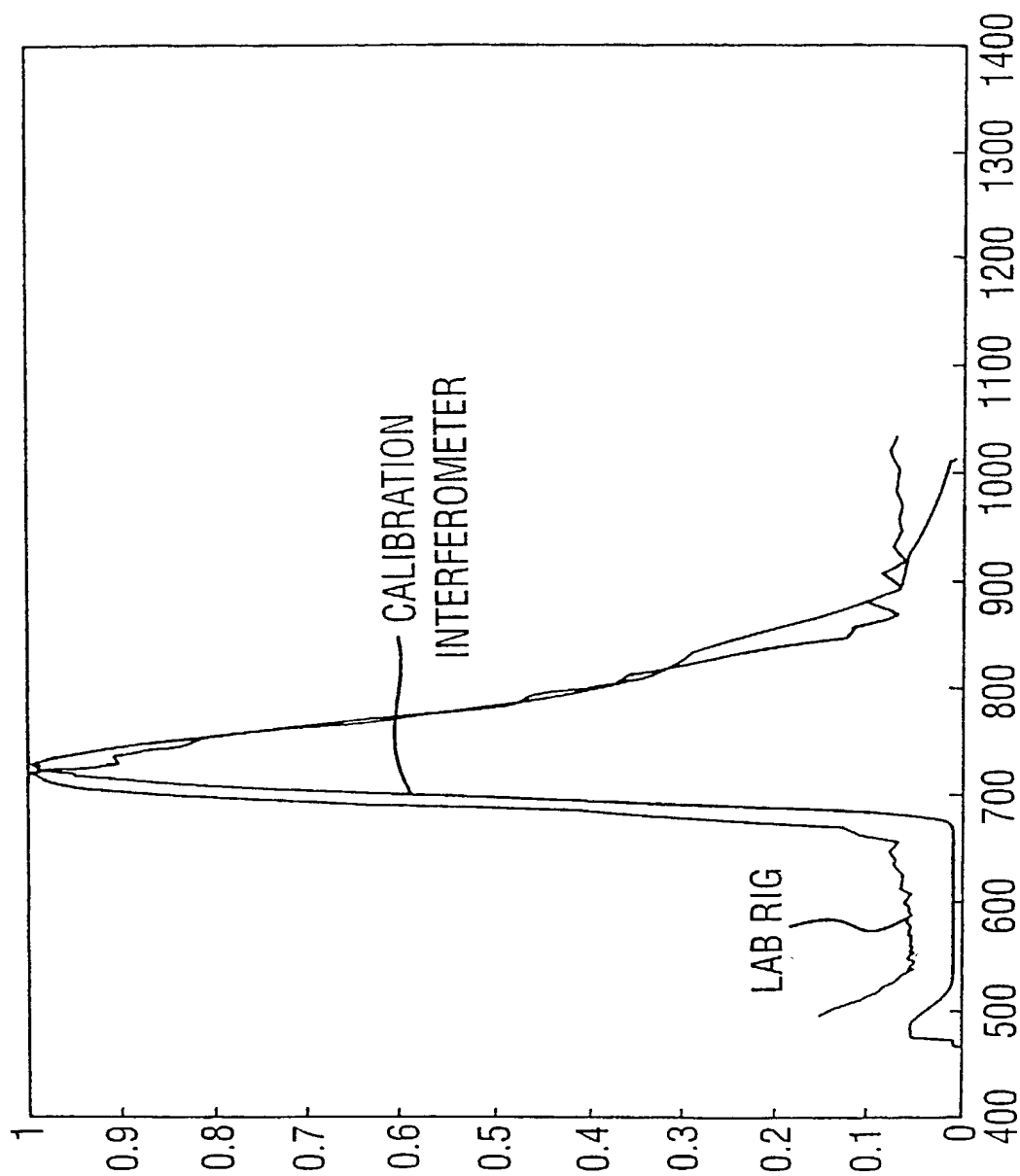
FIG. 18

FIG. 19

DECLARATION AND POWER OF ATTORNEY

, As a below named inventor, I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; I believe I am the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

FOURIER TRANSFORM SPECTROMETER USING AN OPTICAL BLOCK

the specification of which
☐ is attached and/or
☒ was filed as United States Application Serial No._____on <u>January 25, 2002</u>, and was amended on <u>January 25, 2002</u> or
☒ PCT International Application No. PCT/GB00/02898, filed July 27, 2000, and was amended on<u>October 10, 2001.</u>

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate or § 365(a) of any PCT international application(s) designating at least one country other than the United States, listed below and have also identified below, any foreign application(s) for patent or inventor's certificate, or any PCT International application(s) having a filing date before that of the application(s) of which priority is claimed:

Country	Application Number	Date of Filing	Priority Claimed Under 35 U.S.C. 119	
Great Britain	9917610.9	July 27, 1999	☒ YES	☐ NO
			☐ YES	☐ NO

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

Application Number	Date of Filing

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s) or § 365(c) of any PCT International application(s) designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application(s) in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application(s) and the national or PCT International filing date of this application:

Application Number	Date of Filing	Status (Patented, Pending, Abandoned)

I hereby appoint the following attorney and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. **FINNEGAN, HENDERSON, FARABOW, GARRETT & DUNNER, L.L.P., CUSTOMER NUMBER 22,852,** Douglas B. Henderson, Reg. No. 20,291; Ford F. Farabow, Jr., Reg. No. 20,630; Arthur S. Garrett, Reg. No. 20,338; Donald R. Dunner, Reg. No. 19,073; Brian G. Brunsvold, Reg. No. 22,593; Tipton D. Jennings, IV, Reg. No. 20,645; Jerry D. Voight, Reg. No. 23,020; Laurence R. Hefter, Reg. No. 20,827; Kenneth E. Payne, Reg. No. 23,098; Herbert H. Mintz, Reg. No. 26,691; C. Larry O'Rourke, Reg. No. 26,014; Albert J. Santorelli, Reg. No. 22,610; Michael C. Elmer, Reg. No. 25,857; Richard H. Smith, Reg. No. 20,609; Stephen L. Peterson, Reg. No. 26,325; John M. Romary, Reg. No. 26,331; Bruce C. Zotter, Reg. No. 27,680; Dennis P. O'Reilley, Reg. No. 27,932; Allen M. Sokal, Reg. No. 26,695; Robert D. Bajefsky, Reg. No. 25,387; Richard L. Stroup, Reg. No. 28,478; David W. Hill, Reg. No. 28,220; Thomas L. Irving, Reg. No. 28,619; Charles E. Lipsey, Reg. No. 28,165; Thomas W. Winland, Reg. No. 27,605; Basil J. Lewris, Reg. No. 28,818; Martin I. Fuchs, Reg. No. 28,508; E. Robert Yoches, Reg. No. 30,120; Barry W. Graham, Reg. No. 29,924; Susan Haberman Griffen, Reg. No. 30,907; Richard B. Racine, Reg. No. 30,415; Thomas H. Jenkins, Reg. No. 30,857; Robert E. Converse, Jr., Reg. No. 27,432; Clair X. Mullen, Jr., Reg. No. 20,348; Christopher P. Foley, Reg. No. 31,354; John C. Paul, Reg. No. 30,413; Roger D. Taylor, Reg. No. 28,992; David M. Kelly, Reg. No. 30,953; Kenneth J. Meyers, Reg. No. 25,146; Carol P. Einaudi, Reg. No. 32,220;

January 2002

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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